ELIMINATION THD USING 9- LEVEL DC TO AC CASCADE H-BRIDGE MULTILEVEL INVERTER

MOHD FAIZAL BIN MUSTAPHA

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Faculty of Electrical and Electronic Engineering
Universiti Tun Hussien Onn Malaysia

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For my beloved wife, Ainor Izmira bt Mahmood,

Daughter, Amalin Aisyah, Sons, Muhammad Fayyad Aqel, Muhammad Faheem & Muhammad Fatihi, and especially mother Rahmah bt Mohd Noor.

Thank you for your sacrifices and dua'.

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ABSTRACT

Nowaday, electronic devices are very sensitive with harmonics. The needs for a free harmonic and high rating power source is increased to meet the requirement from the industries. This project is to eliminate THD using 9 level cascaded H-bridge of multilevel DC–AC inverter. An Inverter can be broadly classified into single level inverter and multilevel inverter. The result of 9 Cascaded H-Bridge Multilevel Inverter level THD value are compared with 2 level inverter and 5 level Cascaded H-Bridge Multilevel Inverter. The compared multilevel inverter to a single level inverter has advantages like minimum harmonic distortion and higher power output. An implementation of cascaded H-Bridge topology and a sinusoidal pulse with modulation, synthesize a higher quality output power especially with multilevel configuration. Experimental results are included to demonstrate effectiveness of the proposed inverter. This project is to reduce THD contributed by the level of inverter.

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CHAPTER 1

INTRODUCTION

1.0 Project Background

Ac loads require constant or adjustable voltages at their input terminals. When such loads are fed by inverters, it's essential that output voltage of the inverters is so controlled as to fulfill the requirements of AC loads. This involves coping with the variation of DC input voltage, for voltage regulation of inverters and for the constant volts/frequency control requirement. There are various techniques to vary the inverter gain. The most efficient method of controlling the gain (and output voltage) is to incorporate pulse-width modulation (PWM) control within the inverters. The carrier based PWM schemes used for multilevel inverters is one of the most straight forward methods of describing voltage source modulation realized by the intersection of a modulating signal (Duty Cycle) with triangular carrier wavefroms. Multilevel inverters are commonly used for DC to AC conversion in renewable energy conversion [1-3].

1.1 Multilevel Converter

Three main multilevel converter topologies which have been mostly applied in engineering application are known as the cascaded h-bridge converter with separated dc sources, the diode clamp and the flying capacitor and Here, it seems important 'multilevel inverter'. The word 'multilevel converter' refers to the converter itself. The implication of the term reflects that the power can flow in one of two directions. Power which flow from the ac side to the dc side of the multilevel converter is operated in rectification mode. Vice-versa, the power also can flow from the dc side to the ac side of the converter. This mode is called as inverting mode of operation. The 'multilevel inverter' term basically is a 'multilevel converter' that uses the inverting mode of operation.

The multilevel inverter is meant to generate a preferred ac voltage waveform from dc voltages. Figure 1.0 shows an example of ac voltage waveform generated from several dc voltages.

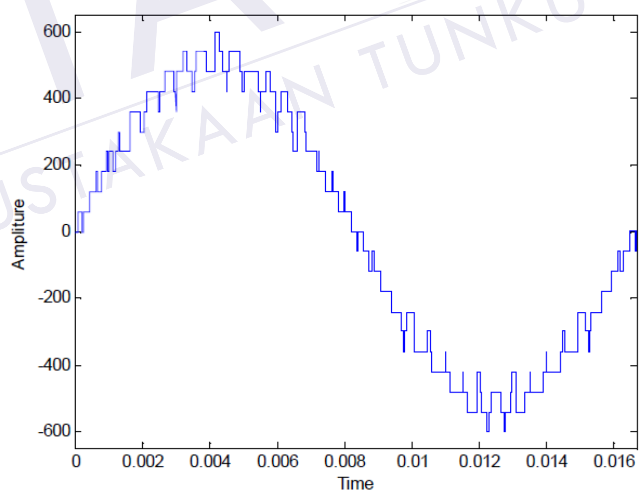

Figure 1.0: Multilevel Inverter Output
Waveform Using 5 Equal DC sources

In above figure, five 120 V dc source produce a pulse waveform with a peak- to-peak voltage of 1200V. Here, the multilevel inverter produces a fair approximation to a sinusoidal waveform. This approximation will get better and better once the amount of dc sources increase. Ideally, once the number of dc sources reach infinity, the pulse waveform will become a pure desired sinusoidal.

On sidering a switching scheme, there are many techniques has been developto be implemented on a multilevel inverter. For example, Sinusoidal PWM, Space Vector PWM, and Selective Harmonic Elimination PWM.

One of the merits of using multilevel inverter is the better total harmonic distortion over the well-known conventional two level inverters. This can be proven by undergo a simulation and experimental exercise.

A multilevel converter has several advantages over a conventional two-level converter that uses high switching frequency pulse width modulation (PWM). The attractive features of a multilevel converter can be briefly summarized as follows.

● Staircase waveform quality: Multilevel converters not only can generate the output voltages with very low distortion, but also can reduce the dv/dt stresses; therefore electromagnetic compatibility (EMC) problems can be reduced.

● Common-mode (CM) voltage: Multilevel converters produce smaller CM voltage; therefore, the stress in the bearings of a motor connected to a multilevel motor drive can be reduced. Furthermore, CM voltage can be eliminated by using advanced modulation strategies such as that proposed in

.

● Input current: Multilevel converters can draw input current with low distortion.

● Switching frequency: Multilevel converters can operate at both fundamental switching frequency and high switching frequency PWM. It should be noted that lower switching frequency usually means lower switching loss and higher efficiency.

Unfortunately, multilevel converters do have some disadvantages. One particular disadvantage is the greater number of power semiconductor switches needed. Although lower voltage rated switches can be utilized in a multilevel converter, each switch requires a related gate drive circuit. This may cause the overall system to be more expensive and complex.

Plentiful multilevel converter topologies have been proposed during the last two decades. Contemporary research has engaged novel converter topologies and unique modulation schemes. Moreover, three different major multilevel converter structures have been reported in the literature: cascaded H-bridges converter with separate dc sources, diode clamped (neutral-clamped), and flying capacitors (capacitor clamped). Moreover, abundant modulation techniques and control paradigms have been developed for multilevel converters such as sinusoidal pulse width modulation (SPWM), selective harmonic elimination (SHE-PWM), space vector modulation (SVM), and others. In addition, many multilevel converter applications focus on industrial medium-voltage motor drives [11, 15, 16], utility interface for renewable energy systems [17], flexible AC transmission system (FACTS) [18], and traction drive systems [19].

1.2 Multilevel inverter

In today market, multilevel inverter comes with many function and advantages. These advantages are focused on improvement in the output signal quality and a nominal power increase in the inverters. This also true if a comparism done to well known two-level inverter[2]. The term multilevel inverter was first introduced back in 1981 by Nabae[3]. By increasing the numbers of levels inverter, the output voltages have more steps generating a staircase waveform, which has reduced harmonics distortion[4]. Figure 1 shows the comparison of the quality between a single-phase two-level inverter is compared to three and nine level voltage multilevel waveform.

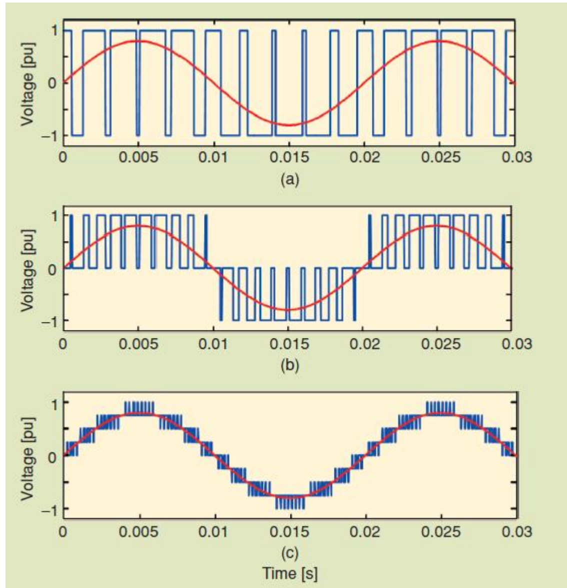

Figure 1.1 : Comparison of output phase voltage waveforms:

(a) two-level inverter, (b) three-level, (c) nine-level. (source:[4])

Multilevel inverters has gained much attention in the application areas of medium voltage and high power owing to their various advantages such as a lower common mode voltage, lower voltage stress on power switch, lower dv/dt ratio to supply lower harmonics content in output voltage and current [5]. Figure 2 shows the overview of the driven application of multilevel inverter.

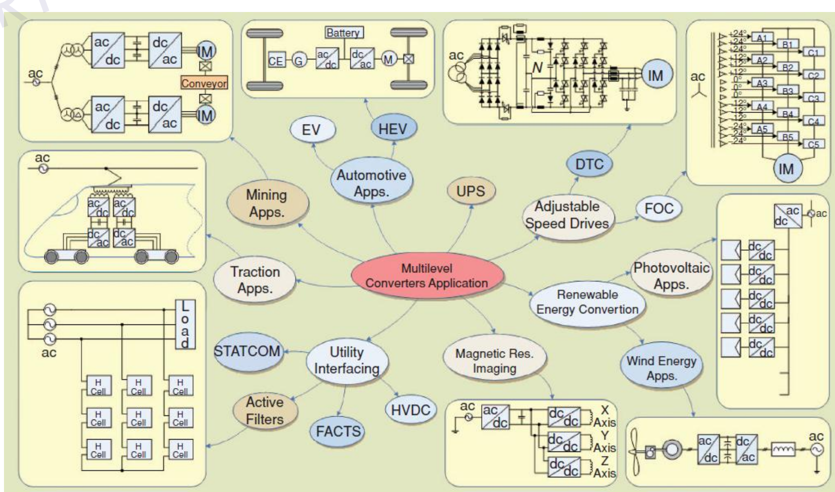

Figure 1 2 : Multilevel inverter driven application overview (source:[4])

Three major multilevel inverter structure which has been mostly applied in industrial application have been emphasized as the diode clamp, the flying capacitor and cascade H-bridge inverter with separated DC sources. Based on these three basic types, a hybrid and a asymmetric hybrid has been developed. Figure 3 shows common multilevel inverter types.

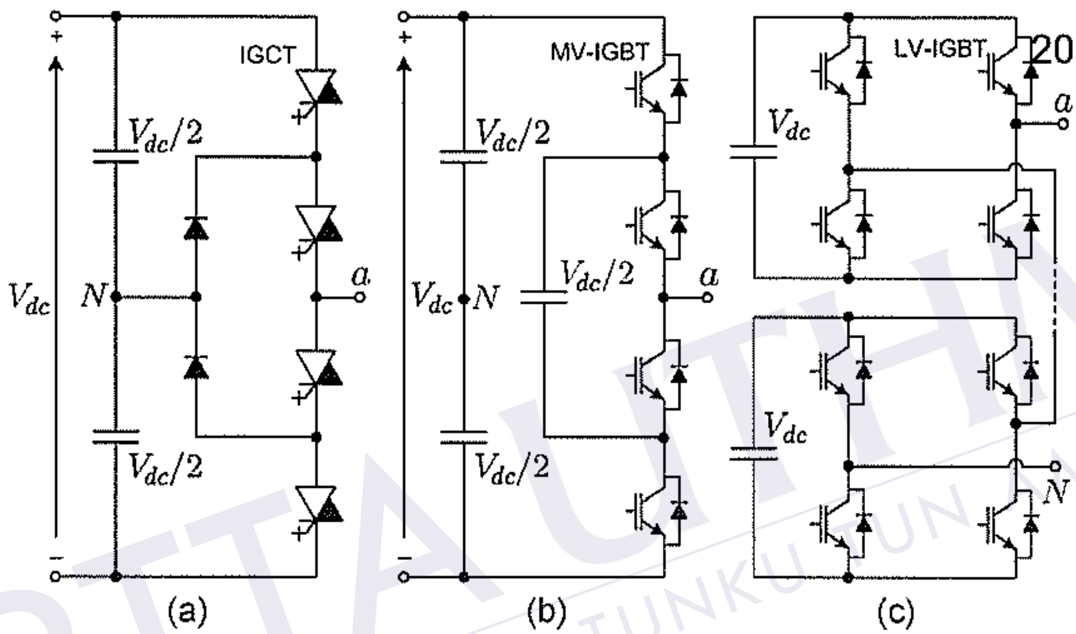

Figure 1.3: Multilevel inverter types: (a) three-level DC-MLI, (b) three-level FC-MLI, (c) five-level CHB-MLI(source:[6])

From this three types, Diode Clamp(DC) inverters and cascaded inverters are most popular. DC inverter used in high power area, mainly are three level inverter[7]. Comparing with two level inverter, DC three level inverters have economic advantages. A multilevel inverter type with less power devices requirement compared to previously mentioned types is known as cascaded H-bridge multilevel inverter (CHB-MLI) and the type is based on the series connection of H-bridge with separate DC source. Since the output terminals of the H-bridges are connected in series, the DC source must be isolated from each other. This topology is a good choice for more than five-level output waveform. Cascade inverter have structurally no problem of dc-link voltage unbalancing but require many separated dc sources in motor drive applications. CHB has a least component requires for a given number of levels[5].

1.3 Merit and Demerit of Multilevel Inverter

Obviously, in recent years multilevel inverter has gained an attention from many areas due to its advantages over the conventional inverters. The ability of the multilevel inverter to utilize a large number of dc sources is one of the merits that it holds. This makes multilevel inverters able to generate high voltages and thus high power ratings. Due to this, the use of bulky and expensive transformers to produces high voltages with conventional 12, 24 and 48-pulse inverter can be abandoned.

Another advantage of multilevel inverter is that it has a reduced Total Harmonic Distortion (THD) with low switching frequencies. Furthermore, due to its lower voltage steps, the value of EMI is lesser and because of its capability to utilize multiple levels on the dc bus, the multilevel inverters able to trim down the voltage stress on each power devices. Additionally, multilevel inverters have higher efficiency because the devices can be switched at low frequency.

Nevertheless, there is still a pitfalls on everything created in this world including multilevel inverter. One of the demerits of multilevel inverters is the isolated power supplies required for each one of the multiconverter. Furthermore, number of components is increased in multilevel inverter compared to traditional inverters. The idea of having larger number of components also means the probability of a device failure will increase.

1.4. The Switching

There are many ways and techniques have been developed to control multilevel inverter switching, from the very basic fundamental switching up to the most advance space vector pulse width modulation switching scheme. But, the most famous and applied by industries out there is the PWM switching control scheme. PWM switching control scheme comes with advantages over the traditional multilevel fundamental switching scheme.

One benefit of PWM methods employing much higher switching frequencies concerns harmonics. The harmonics filtering exercise is much easier and cheaper due to the fact that the undesirable harmonics occur at much higher switching frequencies. Also, the produced harmonics might be above the bandwidth of some actual system. This means that there is no power dissipation caused by the harmonics. On the contrary, multilevel fundamental switching scheme creates harmonics at lower switching frequencies and this increased the complexity of the filtering activity.

1.5 Control Techniques

Multilevel inverter parameter quality such as switching losses and harmonic reduction are basically depends on the modulation strategies applied to the inverter. Several modulation and control techniques have been developed for multilevel inverters. As shown in Figure 1.4, control technique for the multilevel inverter cab be classified into PWM, Selective Harmonic Elimination PWM (SHEPWM) and Optimized Harmonics Stepped Waveform (OHSM). PWM can be classified to open loop and closed loop. For this research, open loop modulation is proposed which will focus on Sinusoidal PWM (SPWM).

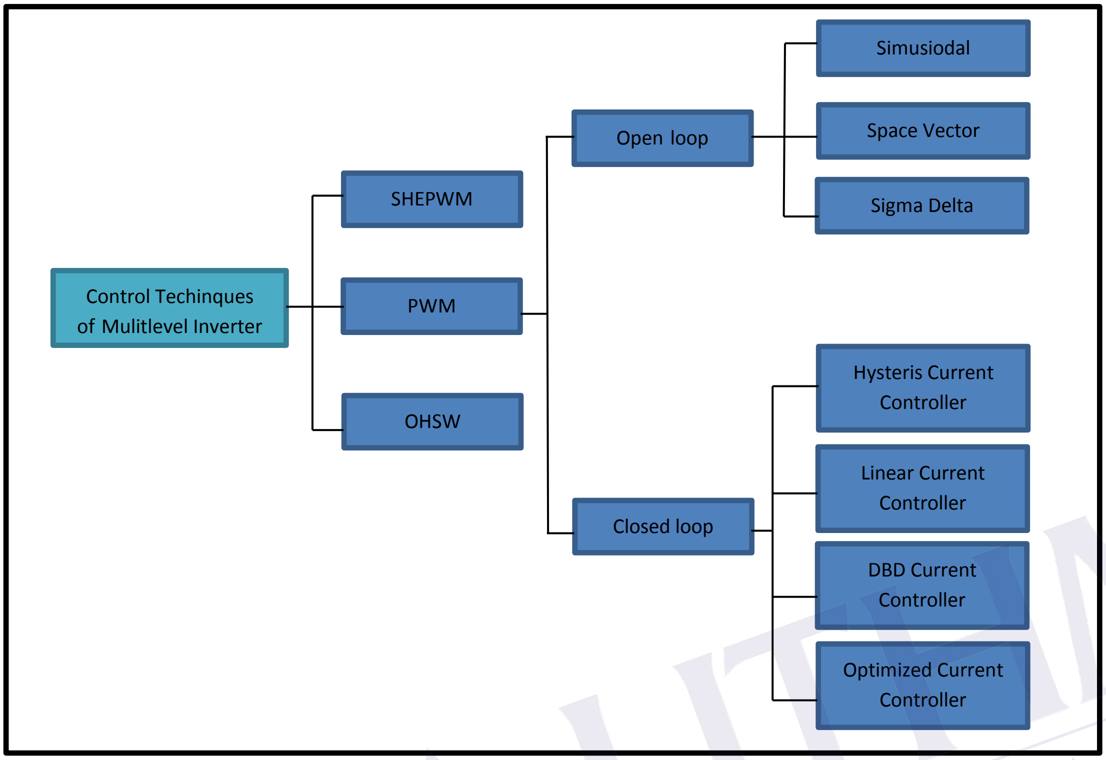

Figure 1.4: Classification of multilevel inverter control scheme (source: [8])

1.6. Problem Statements

One of the important components in the system is the inverter which converts the DC energy stored in the battery banks to AC energy which will then used by consumer or connected to power grid. As the current trend required cleaner power source, higher output power, less losses and almost free harmonics, people are looking forward for better inverter. Thus, a conventional single level inverter is no more relevant to cope with the current trend. Nowadays, industries, researches are focusing to come out with inverter that can overcome the above mentioned issues. As a result a multilevel inverter is created and first published by Nabae in 1980s.

The best performance on higher level of inverter and a promising result on Third Harmonic Injection PWM control technique over SPWM become a motivation for the proposed research. Based on the simulation and several experiment done by previous researches [6][3][7][10], as the level of inverter increases, the degree of complexity on NPC-MLI and FC-MLI hardware is also higher. Now, modern industrial devices are mostly based on electronic devices that are very sensitive to harmonics, even for the induction motor whereby extra heat will be generated with higher harmonic level [16]. Therefore, the proposed work is believed shall synthesize a better quality result with Third harmonic Injection PWM scheme but with better topology which required lesser components and hardware complexity in hardware devolepment.

Ever since the industrial revolution in 1800, the demand for energy is increased dramatically, especially in developing countries in-line with the economy growth. Modern industrial machineries, electric vehicles, home appliances and public healthcare contribute to the high demand of energy. The recent policies situation in World Energy Outlook 2012 (WEO 12) revealed that "several fundamental trends persist: energy demand and CO2 emission rise even higher; energy market dynamics are increasingly determine by emerging economies; fossil fuels remain the dominant source; and providing universal energy access to the world's poor countries continues to be an elusive goal".

1.7 Project Objective

There are three objective have been set for this work to be achieved at the end of the activities.

To simulate the modelled CHB-MLI performance with the implementation of Third harmonic Injection PWM control technique.

To analyse the multilevel inverter performance in term of THD, fundamental and harmonic rms of the voltage and current for different levels of harmonic injection.

1.8.Project Scopes

The scopes of this project are:

- This research will be focus on the way to development of 9 level multilevel inverter.
- Implementation of Cascade H-Bridge MLI type and Third harmonic Injection PWM control technique.
- Studies on improvement of total harmonic distortion among other level of harmonic injection levels.

CHAPTER 2

LITERATURE REVIEW

2.1 Theories

2.1.1 Inverter

A device that converts DC power into AC power at desired output voltage and frequency is call an Inverter. Phase controlled converters when operated in the inverter mode are called line commutated inverters. But line commutated inverters require at the output terminals an existing AC supply which is used for their commutation. This means that line commutated inverters can't function as isolated AC voltage sources or as variable frequency and waveform on the AC side of the line commutated inverters can't be changed. On the other hand, force commutated inverters provide an independent AC output adjustable voltage and frequency. Based on their operation the inverters can be broadly classified into

Voltage Source Inverters(VSI)

Current Source Inverters(CSI)

A **voltage source inverter** is one where the independently controlled ac output is a voltage waveform. A **current source inverter** is one where the independently controlled ac output is a current waveform. Some industrial applications of inverters are for adjustable- speed ac drives, induction heating, stand by air-craft power supplies, UPS uninterruptible power supplies) for computers, HVDC transmission lines etc. An inverter changes DC voltage from batteries or solar panels, into standard household AC voltage so that it can be used by common tools and appliances. Essentially, it does the opposite of what a battery charger or "converter" does. DC is usable for some small appliances, lights, and pumps, but not much else. Some DC appliances are available, but with the exception of lights, fans and pumps there is not a wide selection. Most other 12 volt items we have seen are expensive and/or poorly made compared to their AC cousins. The most common battery voltage inputs for inverters are 12, 24, and 48 volts DC - a few models also available in other voltages. There is also a special line of inverters called a **utility intertie** or grid tie, which does not usually use batteries - the solar panels or wind generator feeds directly into the inverter and the inverter output is tied to the grid power. The power produced is either sold back to the power company or (more commonly) offsets a portion of the power used. These inverters usually require a fairly high input voltage - 48 volts or more. Some, like the Sunny Boy, go up to 600 volts DC input.

Voltage source inverter (VSI) with variable DC link in Figure 2.1. DC link voltage is varied by a DC-to DC converter or controlled rectifier.Generate "square wave" output voltage.•Output voltage amplitude is varied as DC link is varied. Frequency of output voltage is varied by changing the frequency of the square. wave pulses.DC

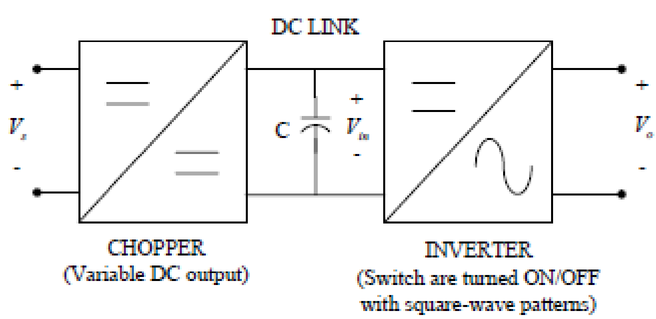

Figure 2.1 Voltage source inverter(VCI) with variable DC link.

2.1.2 Cascaded H-bridge Multilevel Inverter

As the name suggest, a cascaded H-bridge inverter is constructed by a series of h- bridge inverter in cascade configuration. Basically, a three-phase inverter has a same structure as single H-bridge inverter which use unipolar PWM. This type of topology is relatively a new configuration after the NPC and FC structure [27]. The topology proposed a concept with a uses of separate dc source connected for each H-bridge to generate an ac voltage waveform. The final ac output waveform is produced by cascading the individual H-bridge output waveform.

Figure 2.2 illustrates an m-level cascaded H-bridge inverter. Three different output waveforms will be generated for each inverter level with an appropriate control scheme for the switches: $+V_{dc}$, 0 and $-V_{dc}$. With S1 and S2 turned on, +Vdc will be produced, while –Vdc can be realize with by switched on S2 and S3. The 0 output voltage will be generated by switching on all S1, S2, S3 and S4 switches. The sum of different individual h-bridge inverter outputs connected in series synthesized the final ac output voltage of the multilevel inverter. An equation of m=2s+1 determine the number of voltage levels m in a cascaded H-bridge inverters where s is the number of independent dc source connected to the individual H-bridge inverter. For instance, an 11 level cascaded h-bridge inverter with independent dc source is illustrated in Figure 2.3. The final output for a single phase van is a sum of va1, va2, va3, va4 and va5.

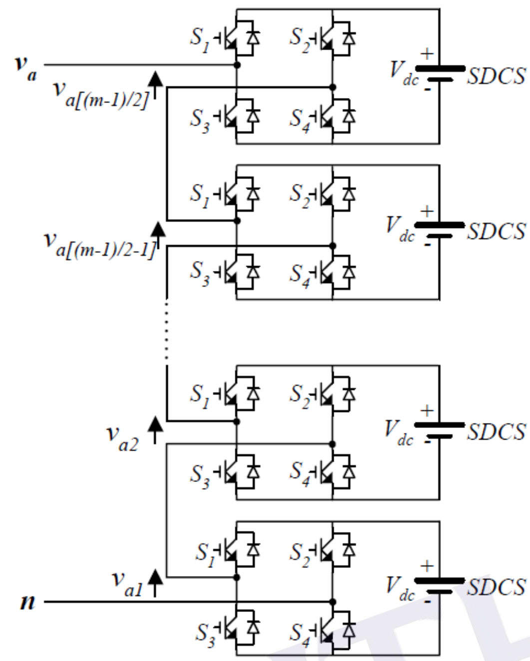

Figure 2.2: M-Level Single Phase Cascaded H-Bridge Multilevel Inverter

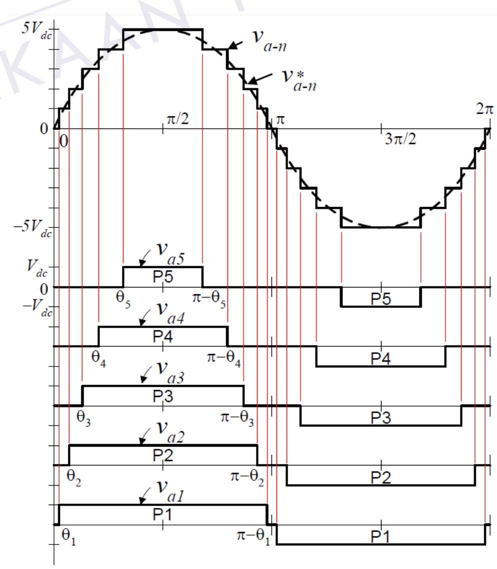

Figure 2.3: Cascaded H-Bridge Multilevel Inverter Generalize Output Waveform

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